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The Reliability Analysis of PV Panels Installed in KP Region

Jawad Ahmad
MSc. Student USPCAS-E,EESE department, UET Peshawar
engr.jwd89@gmail.com
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***Abstract*--** Reliability and long term performance of photovoltaic (PV) system is of vital importance in switching from conventional sources to sustainable one. Design, study and analysis of key components in a photovoltaic power system starting from generation of power to withstands number of climatic stresses and uninterrupted power supply plays a key role. One of the key elements in photovoltaic system is photovoltaic module. Also power generated in photovoltaic system is dependent on a source of energy that changes in every instant and with the passage of time during its operation .Hence it is paramount to build a long lasting photovoltaic module and analyze characteristics of the PV module under various conditions. This paper presents an efficient PV module based on PV equivalent circuit model using MATLAB/Simulink, and compared the simulated model results with manufacturer's specifications like peak current, peak voltage, open circuit voltage and short circuit current .Also the performance of the module under variation of series resistance, irradiation, and temperature are analyzed. Data from five different areas across KP are noted and the results were Simulated and compared with the rated data.

Keywords: Matlab/Simulink, Irradiation, PV Module, Temperature.

Nomenclature used:
AM--- Air mass
A ---- Current in Amperes
W/m^2 --- Watts per meter square
KW ---Kilowatts
V --- Voltage
I --- Current
I_{sc}--- Short Circuit Current

V_{oc} --- Voltage Open Circuit
MWh ---- Mega Watt Hour
FF --- Fill Factor
STC --- Standard Test Conditions (25 °C, 1000 W/m^2)
G --- Irradiance
I_m --- Maximum current from PV
V_m --- Maximum voltage from PV
In^2 --- Inches square
KPK --- Khyber Pakhtunkhwa.

I. Introduction

Since 2008 Pakistan has experienced immense energy crisis, which resulted in 18 hours' power fall in remote area and around 12 hours in urban areas. Pakistan is blessed with a high potential of solar energy resources and is estimated that the annual sunshine in the country is about 3000-3300 hours [1], with daily effective sun-shine hours in most of its places are 7 to 8 hours [4]. Harvesting that potential the country has been flooded with different standards of PV panels, inverters, and batteries to fulfill the consumer energy demand. Initially due to lack of regulatory authorities mostly quality and installation guidelines were compromised.

The aim of this paper is to design a PV model, study the effect of different parameters on the system and collect data from different sites across KP, Pakistan for possible degradation and their performance variation from rated values during its course of operation, plot P-V and I-V graphs against their rated values. As for the large scale success of PV systems the long lasting performance, effective cost and ability to provide the desired results even in the severe conditions is paramount [3].

The end result concluded that raw material used in PV panels, system installing methodology, Vandalism, Array configuration and different climatic conditions have significantly affected the overall system performance and reliability.

II. PV Array's Equivalent circuit in MATLAB Simulink

The electrical equivalent circuit of photo Voltaic cell is shown in figure 1 (a). Here current in the cell are represented by Ip. Series and parallel resistances are represented by Rs and Rsh, these are the intrinsic resistances of the cell. In normal operating conditions the value of Rs are very low as compared to Rsh. That's why most the generated current passes through Rs. For the simplification purpose Rs is ignored [4]. In actual practices, PV cells are arranged in large groups which is called PV modules and their configuration is either series or parallel to form PV arrays, which produces electricity in PV generating plants. PV arrays equivalent circuit is shown in the figure 1.

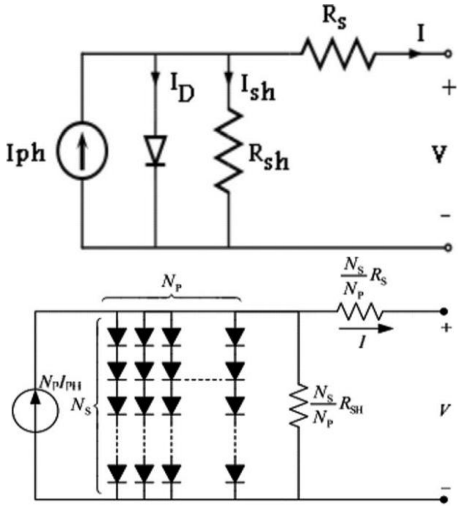


Figure 1: a) Solar Cell equivalent circuit (b) Solar Array equivalent circuit

The characteristics equation of voltage-current is provided as [5]

$$I_p = [I_{sc} + K_i(T - 298)] \times G/1000$$

Where,

I_p --- photo current (A)

I_{sh} --- Short circuit current (A)

K_i--- Short circuit current of cell at 25 ˚C and 1000 W/m^2

T --- Operating temperature (K)

G --- Solar irradiation (W/m^2)

Also the module reverses saturation current I_{rs}:

$$I_{rs} = I_{sc} / [\exp(q\, V_{oc}/N_s k n\, T) - 1]$$

As the cell temperature changes the module saturation current varies accordingly, the module saturated current expression is given as:

$$I_0 = \frac{I_{sc} + K_i(T - 298.15)}{\exp\left(\frac{q(V_{oc} + K_v(T - 298.15))}{aKTN_s}\right) - 1}$$

Where,

T --- Nominal temperature = 298.15 K

V_{oc} --- Open circuit voltage (V)

PV module output current is,

$$I = N_p \times I_p - N_p \times I_o \times \left[\exp\left(\frac{\frac{V}{N_S} + I \times \frac{R_S}{N_P}}{n \times V_t}\right) - 1\right] - I_{sh}$$

Where,

q --- Electron charge, = 1.6 × 10^{-19} C

N_s --- Number of cells connected in series

n --- The ideality factor of the diode

k --- Boltzmann's constant, = 1.3805 ^{23} J/K

III. Reference Model

Solar power module of 100 W is taken as reference module, based on the above mathematical equations the Simulink model developed is shown the figure 2 and 3.

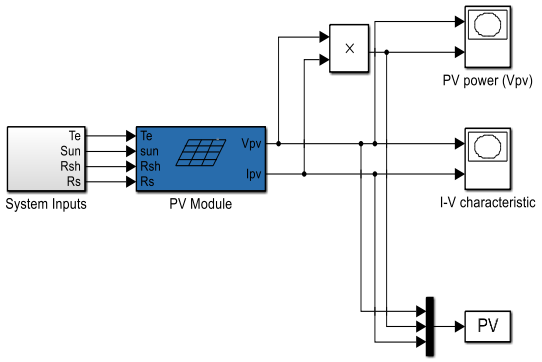


Figure 1: Block diagram of PV System

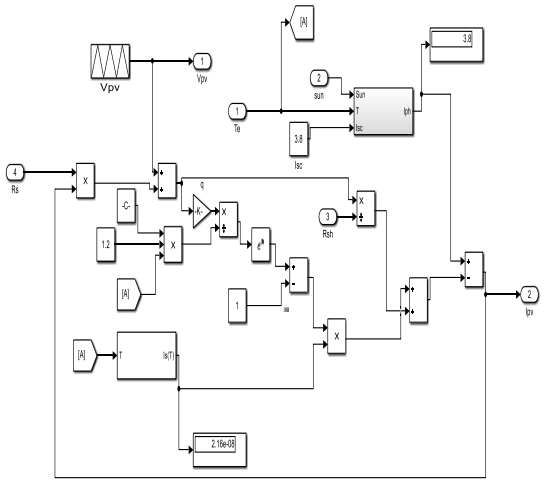


Figure 2: Mathematical model for PV module

The figure 3, shows the block diagram of PV system. The input parameters that change the entire system output are Temperature, Solar irradiance, Parallel resistance and series resistance of the circuit. The second figure 3.4, shows the PV

array mathematical model including the fundamental components of current source, shunt resistance and parallel resistor and diode in Simulink environment with tags. The value of constants as previously enlisted are feed in Simulink model.

IV. AND PV CURVES OF DIFFERENT SITES ACROSS KP

The ratings of the system and their respective I-V and P-V curves of different panels at different sites are as below;

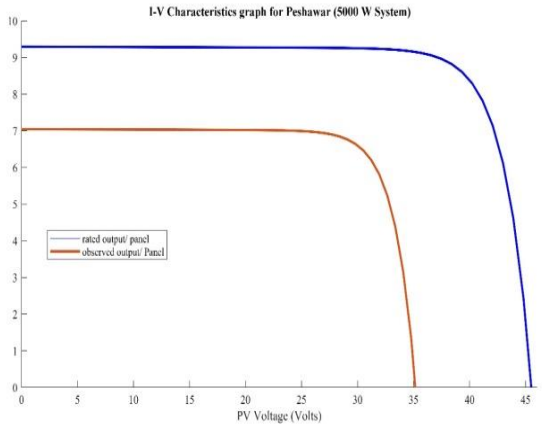
A. Peshawar

Peshawar Pakistan (latitude 34.0151° N, longitude 71.5249° E), This system was installed in the mid of 2014 by local technicians and was placed on the roof top of the house, it has an installed capacity of 5.2 kW with 16 poly crystalline solar panels each of 325 W rating, 2 panels were connected in series to form a string and the strings were then connected in parallel. 84 V DC input were given to the inverter, the inverter had a rating of 5KW and had a battery bank, comprises of 8 batteries, each of 150 Ah. Data collected is shown in the given table 1.

TABLE 1: MODELING PARAMETERS FOR PESHAWAR SITE

S.No	1	2	3
Module temperature	45 ℃	45 ℃	45 ℃
Ns	60	60	60
Np	1	1	1
G W/m^2	835	830	840
Im (Rated)	8.66 A	8.66 A	8.66 A
Vm (Rated)	36.5 V	36.5 V	36.5 V
Pm (Rated)	325 W	325 W	325 W
Im (Noted)	7.01 A	6.98 A	7.03 A
Vm (Noted)	35.1 V	35 V	35.1 V

The readings were taken from various panels during my visit to the site. I-V and P-V curves were plotted for the rated and actual readings. As the actual measured readings were almost identical, so here in this section, one I-V and P-V curve has been plotted for the analysis as shown in figure 4.



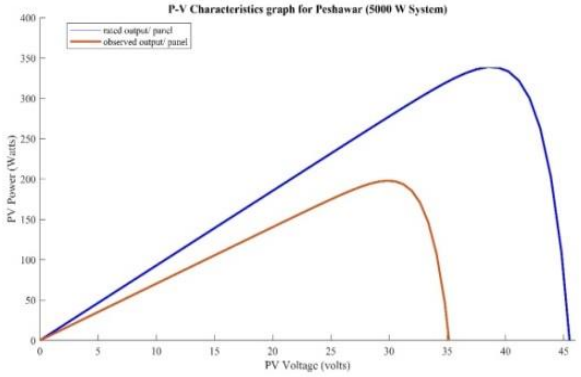


Figure IV: I-V and P-V Curve of PV for Peshawar site

As from the above curves in figure 4.5, it has been shown that the performance of all the panels on ground has varied by a reasonable margin from its rated values. From this analysis we can forecast the performance degradation of PV modules in coming years.

B. Swat

Swat Pakistan (latitude 35.2227° N, longitude 72.4258° E). The system was installed in the start of 2013 by local technicians according to the owner and was placed on the roof top of the house, it has an installed capacity of 3 kW with 12 poly crystalline solar panels each of 250 W rating, 2 panels were connected in series to form a string and the strings were then connected in parallel. 72 V DC input were given to the inverter, the inverter had a rating of 4 KW and had a battery bank, comprises of 4 batteries, each of 110 Ah. The collected data has been shown in the below table 2.

TABLE 2: MODELING PARAMETERS FOR SWAT SITE

S.No	**1**	**2**	**3**
Module temperature	38 ℃	38 ℃	38 ℃
Ns	72	72	72
Np	1	1	1
G W/m2	980	965	972
Im (Rated)	6.38 A	6.38 A	6.38 A
Vm (Rated)	36 V	36 V	36 V
Pm (Rated)	250 W	250 W	250 W
Im (Noted)	5.98 A	6.01 A	5.96 A
Vm (Noted)	34.5 V	34.48 V	34.49 V

The readings were taken from various panels during my visit to the site. I-V and P-V curves were plotted for the rated and actual readings. As the actual measured readings were almost identical, so here in this section, one I-V and P-V curve has been plotted for the analysis as shown in figure 5.

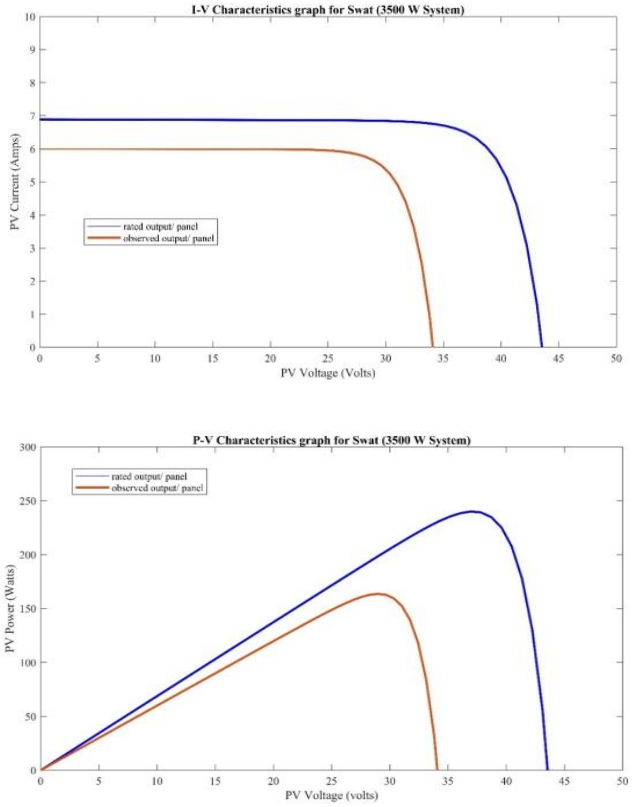


Figure 5: I-V and P-V Curve of PV for Swat site

As from the above curves in figure 4.5, it has been shown that the performance of all the panels on ground has varied by a reasonable margin from its rated values

C. Mardan

Mardan Pakistan (latitude 34.1989° N, longitude 72.0231° E). The system was installed in December,2013 by local technicians and was placed on the roof top of the house, it has an installed capacity of 4.32 kW with 16 poly crystalline solar panels each of 275 W rating, 2 panels were connected in series to form a string and the strings were then connected in parallel. 60.4 V DC input were given to the inverter, the inverter had a rating of 4 KW and had a battery bank comprises of 4 batteries, each of 110 Ah. Data collected is shown in the given table 3.

TABLE 3: MODELING PARAMETERS FOR MARDAN SITE

S.No	**1**	**2**	**3**
Module temperature	44 °C	44 °C	44 °C
Ns	72	72	72
Np	1	1	1
G W/m^2	884	859	875
Im (Rated)	8.72 A	8.72 A	8.72 A
Vm (Rated)	30.8 V	30.8 V	30.8 V
Pm (Rated)	270 W	270 W	270 W
Im (Noted)	6.15 A	6.2 A	6.17 A
Vm (Noted)	28.5 V	28.43 V	28.47 V

The readings were taken from various panels during visit to the site. I-V and P-V curves were plotted for the rated and actual readings. As the actual measured readings were almost identical, so here in this section, one I-V and P-V curve has been plotted for the analysis as shown in figure 6.

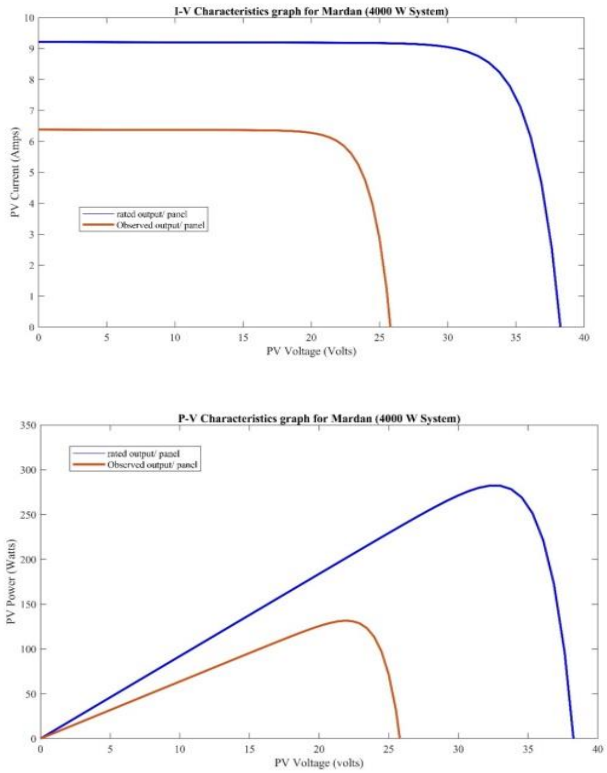


Figure 6: I-V and P-V Curve of Mardan site

As from the above curves in figure 4.7, it has been shown that the performance of all the panels on ground has varied by a reasonable margin from its rated values.

D. Swabi

Swabi (latitude34.1241° N, longitude 72.4613° E). The system was installed in March,2014 by local technicians and was placed on the roof top of the house, it has an installed capacity of 2.4 kW with 8 mono crystalline solar panels each of 300 W rating, 2 panels were connected in series to form a string and the strings were then connected in parallel. 78 V DC input were given to the inverter, the inverter had a rating of 2.4 KW and had a 2 batteries backup, each of 110 Ah in table 4.

TABLE 4: MODELING PARAMETERS FOR SWABI SITE

S.No	**1**	**2**	**3**
Module temperature	43 °C	43 °C	43 °C
Ns	60	60	60
Np	1	1	1
G W/m^2	903	898	890
Im (Rated)	8.3 A	8.3 A	8.3 A
Vm (Rated)	36.1 V	36.1 V	36.1 V
Pm (Rated)	300 W	300 W	300 W

Im (Noted)	7.03 A	6.99 A	7.01 A
Vm (Noted)	31.9 V	31.9 V	31.88 V

The readings were taken from various panels during my visit to the site. I-V and P-V curves were plotted for the rated and actual readings. As the actual measured readings were almost identical, so here in this section, one I-V and P-V curve has been plotted for the analysis as shown in figure 7.

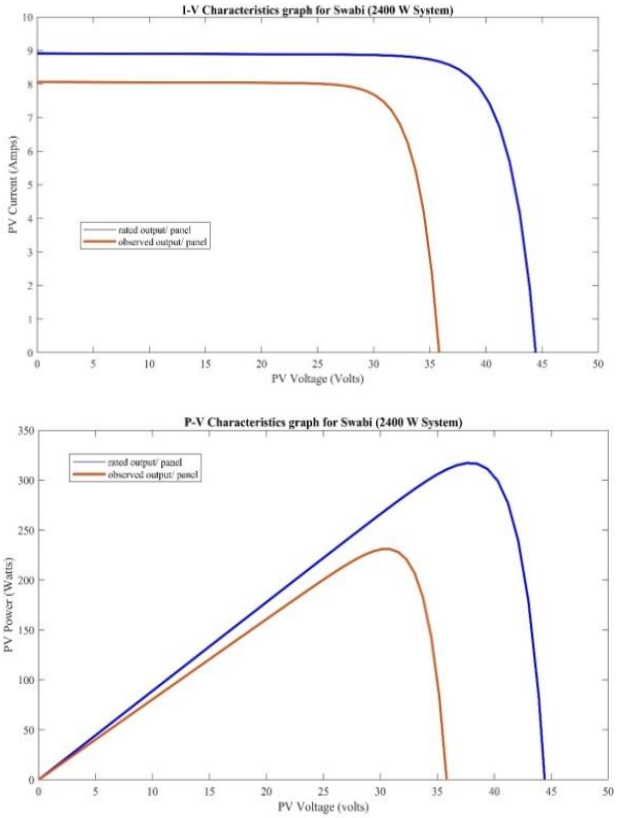


Figure 7: I-V and P-V Curve of PV from Swabi site

As from the above curves in figure 4.8, it has been shown that the performance of all the panels on ground has varied by a reasonable margin from its rated values.

4.4. Lower Dir

Lower Dir Malakand division Pakistan (latitude 34.9161° N, longitude 71.8097° E). This system was installed in April,2013 by local technicians and was placed on the roof top of the house, it has an installed capacity of 4160 kW with 16 poly crystalline solar panels each of 260 W rating, 2 panels were connected in series to form a string and the strings were then connected in parallel. 62 V DC input were given to the inverter, the inverter had a rating of 5 KW and had a 4-battery backup, each of 150 Ah.

TABLE 5: MODELING PARAMETERS FOR LOWER DIR SITE

S.No	**1**	**2**	**3**
Module temperature	37 °C	37 °C	37 °C
Ns	60	60	60
Np	1	1	1
G W/m^2	954	961	949
Im (Rated)	8.3 A	8.3 A	8.3 A
Vm (Rated)	31.1 V	31.1 V	31.1 V
Pm (Rated)	260 W	260 W	260 W
Im (Noted)	7.05 A	7.01 A	6.99 A
Vm (Noted)	28.03 V	28.05 V	28.00 V

The readings were taken from various panels during my visit to the site. I-V and P-V curves were plotted for the rated and actual readings. As the actual measured readings were almost identical, so here in this section, one I-V and P-V curve has been plotted for the analysis as shown in figure 8.

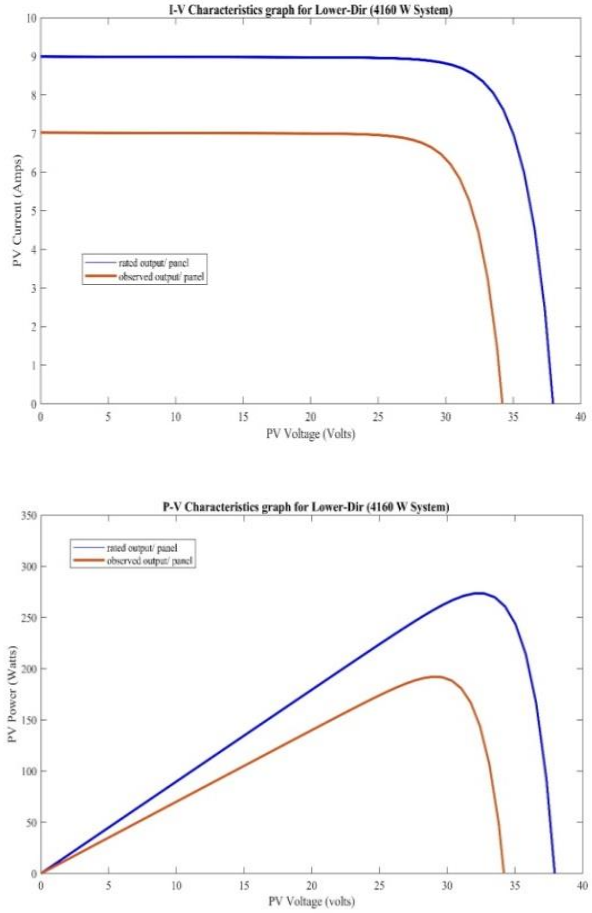


Figure 8: I-V and P-V Curve of PV from Lower Dir site

As from the above curves in figure 4.9, it has been shown that the performance of all the panels on the ground has varied by relatively fewer margins from its rated values.

CONCLUSION

To illustrate the long term performance and variation from the rated data over a course of time during operation, I selected five different sites across KPK, visited the all the sites and noted its system capacities, installation Methods and checked for all possible visual degradation since from their installation till date. I put all the acquired data into my

MATLAB model with the temperature, Series and Parallel combination noted from each site and acquired the I-V and P-V curves of the noted data and compared with the rated capacities of each panel mention on its nameplate. It reveals the decrease in power capacities over a course of time as some cells perform poorly after ye.ars of operation.

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